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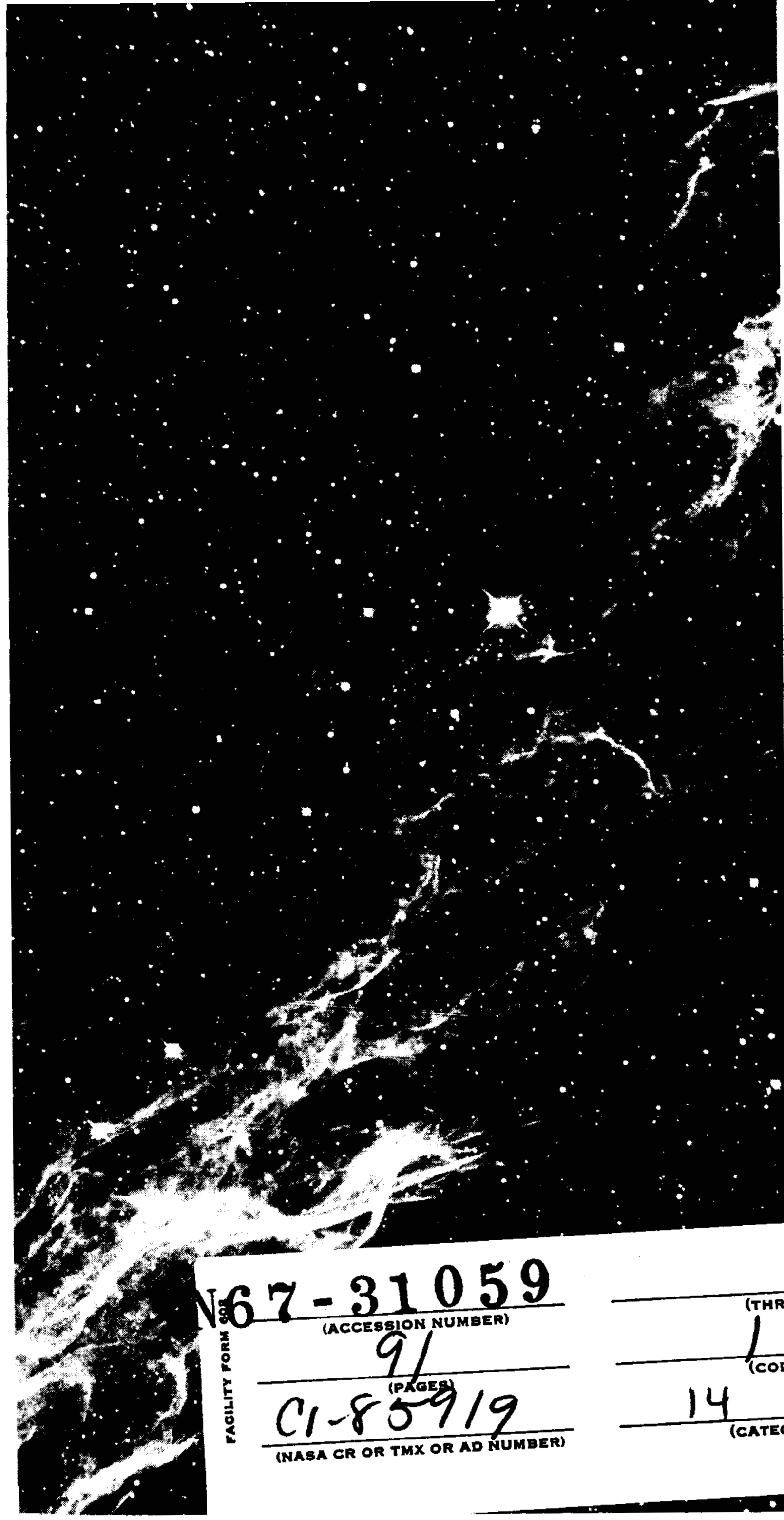

Report No. P-20

SUGGESTED MEASUREMENT/INSTRUMENT REQUIREMENTS FOR LUNAR ORBITER BLOCK III

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SUMMARY

This report describes typical scientific measurement and instrument requirements for Lunar Orbiter Block III missions. These missions are planned for the period beyond 1972. The purpose of the study has been to organize information on remote sensing instrument requirements (excluding the metric camera), as an input to a subsequent and independent Phase A study. The metric camera has been indicated where required in this study, but the specifications for it have been undertaken by the Langley Research Center.

In conducting this study, it was necessary to take a broad approach and to consider first what measurements, both orbital and surface, were necessary to completely answer the 15 scientific questions about the moon, posed originally by the Space Science Board (SSB 1965). This approach was taken as far as was necessary to permit the determination of which measurements could be best made from a spacecraft in lunar orbit, and those measurements best made on the lunar surface. Only the orbital measurements were then considered for determination of the detailed instrument and measurement requirements. Thus, the surface instrument requirements for lunar exploration specifically have been excluded from the study.

For orbital missions, a preliminary assignment of suitable types of instruments was made from a list of remote-sensing instrumentation which had been generated from the literature. The final phase of the study involved the derivation of a set of suggested measurement and instrument specifications for all of the considered instruments. The decision process utilized at each stage of the study has been that of consensus by a group of scientists. Clearly the decisions are open to review and criticism by the scientific community.

A total of 30 scientific questions, derived from the original 15 SSB questions, have been considered in this study. Of these 30 questions, orbital mission measurements can contribute to answering 22. However, only four of the 22 orbital-related questions could be completely answered by data taken from orbital missions. In making measurements from orbit there are six basic types of measurement requirements which are related to the 13 spacecraft instruments suggested for consideration in planning Lunar Orbiter Block III missions. These measurement requirements, instruments, and instrument purposes, are shown in Table S1.

Table S1

MEASUREMENT/INSTRUMENTATION/PURPOSE RELATIONSHIPS FOR LOB III

Measurement Requirements	LOB III Instruments	Instrument Purpose
Geometric shape	1. Radar altimeter	Spacecraft altitude
Chemical elemental variation	2. X-ray spec.	Elemental composition
	3. Solar X-ray monitor	Solar X-ray monitoring
	4. Vidicon camera	Percentage shadowing (in conjunction with X-ray spectrometer)
(Surface measurements are also necessary.)		
Material distribution*	2,3,4	Same as above
	5. Multispectral imager	Rock unit identification
	6. Vis-UV spectrometer	Rock signatures
	7. IR spectrometer	Rock signatures
(Surface measurements are also necessary.)		
Active volcanism	8. IR radiometer (3-10μ)	Volcanic temperature detection
	9. IR-Vis-UV gas spectrum analyzer	Volcanic gas analysis
Tectonic processes*	10. IR radiometer (8-28μ)	Thermal mapping
(Surface measurements are also necessary.)		
Atmospheric gases	11. Quadrupole mass spectrometer	Gas analysis
	12. Redhead pressure gauge	Atmospheric pressure

*Metric camera (photographic mapping) is necessary.

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SUGGESTED MEASUREMENT/INSTRUMENT REQUIREMENTS FOR LUNAR ORBITER BLOCK III

1. INTRODUCTION

The purpose of the study has been to determine typical scientific measurement and instrument requirements for post-Apollo lunar orbital missions. The resulting instrument specifications were to be used as an input to an independent Phase A Lunar Orbiter Block III mission study.

In planning for the exploration of the moon, it is necessary first of all to define very clearly the scientific goals as well as the basic questions which must be answered in order to accomplish these goals. An excellent initial statement defining the major scientific objectives and key questions was made by the Space Science Board during its summer meeting at Woods Hole, Massachusetts, in 1965 (SSB 1965) and by the NASA working groups at the Falmouth Conference (Falmouth 1965). These have been taken as the basic scientific objectives for the study and are presented in Appendix A.

Since the SSB meeting, however, the lunar objectives and questions have been the subject of much discussion, and also have been the basis for several studies of lunar exploration. Repeatedly, NASA has cautioned against accepting these objectives and questions as being either fixed or final, and has indicated that they should be changed, if necessary, to provide for a better and more complete exploration program. This philosophy has been followed here in the further interpretation of the questions presented in Appendix B.

To accomplish the primary scientific objectives of lunar exploration, it will be necessary to obtain measurements by means of orbiter and lander spacecraft, in both unmanned and manned missions. However, the scientists who have been involved in planning lunar exploration, have stated that, in the foreseeable future, less than 1 percent of the moon's surface will be explored from lander spacecraft. Therefore, it is necessary to plan for the investigation of most areas of the moon by means of <u>orbital spacecraft missions</u>.

Orbiter missions are limited somewhat, and should be considered primarily as a mode for the measurement or detection of variations in gross properties, and for lunar reconnaissance. Orbiter missions should not be considered as a means for the acquisition of absolute data about the moon. Furthermore, a fairly large amount of ground truth information will be required in order to interpret, correlate, and extrapolate the data obtained from orbiter missions. Three basic types of lunar orbiter missions are planned for the remote investigation of the moon. They are designated as Lunar Orbiter Block I, II, and III. Each block will be operational in a different time frame (NASA 1966).

LOB I missions already have been successful, with additional flights planned through 1967. These photographic missions are principally conducted for the purpose of selecting landing sites for the Apollo spacecraft. At present, five LOB I missions have been approved. It is anticipated that a large portion of the equatorial region of the moon will have been photographed prior to the Apollo flight and landing on the moon.

Preliminary analysis of the photographs taken by LOB I have provided valuable new information about the moon. Some of the important discoveries include:

(1) The backside of the moon has large fracture zones which are not comparable to those observed on the side which faces the Earth.

(2) Volcanic features are in abundant evidence.

(3) Mass wasting is in evidence.

(4) Small craters have been detected in large numbers within areas which formerly were thought to be quite smooth.

Lunar Orbiter Block II missions are scheduled to begin in 1968, and will continue until 1971. These missions will provide an increased payload capability over LOB I, but within the same basic spacecraft design. The missions probably will extend the photographic coverage to sites of interest at higher altitudes, and also may carry several types of remote sensors. The remote sensors, if employed, will be used primarily in testing their applications as well as to gather preliminary data about the lunar surface. LOB II flights are presently designated as inclined orbital missions with the primary emphasis on mapping surface areas in support of the follow-on SAA (Saturn Apollo Applications) surface missions.

The third category of orbital missions presently proposed is the Lunar Orbiter Block III, which is planned for the period from 1972 onwards. These missions will be conducted in an effort to map a large proportion of the lunar surface by the use of both photographic and remote sensing techniques. All types of remote sensors which have been tested and determined to be applicable to lunar exploration, probably will be utilized during these missions.

This study has provided specifications of remote sensing instruments for Lunar Orbiter Block III missions. Instrument descriptions are provided in Section 2 and the development of the measurement requirements is discussed in Section 3.

2. TYPICAL INSTRUMENT REQUIREMENTS

The scientific base used to derive the Lunar Orbiter Block III instrument requirements are the 30 questions expressed in terms of measurable quantities listed in Table 1, and in Table 2 are expressed the basic relationships between these questions and the specified orbiter instruments. The methods

Table 1

SCIENTIFIC QUESTIONS EXPRESSED IN TERMS OF MEASURABLES

1. MASS DISTRIBUTION AND BODY DENSITY

1.1 What is the intensity of the field of gravity about the moon with respect to its center of mass?

1.2 What are the depths and shapes of major discontinuities within the moon?

1.3 What is the relative location and elevation of a specified number of different points on the lunar surface?

1.4 What is the mass distribution of the moon in regard to its shape, present tidal effect, and rigidity?

2. CHEMICAL AND PHYSICAL PROPERTIES OF SURFACE MATERIALS

2.1 Do the most abundant elements known on the earth (e.g., silicon, magnesium, oxygen, iron, etc.) vary over the lunar surface on the order of ± 10 percent from mare to mare, highland to highland, from mare to highland, and regionally ($\sim$ 100 miles) within these areas?

2.2 In what percentages are the most abundant elements (e.g., silicon, oxygen, magnesium, iron, etc.) present on the surface of the Moon?

2.3 What is the regional distribution of materials and rock types on the lunar surface (e.g., lava, granite, pyroclastic material, etc.)?

3. PROCESSES OF THE MOON

3.1 Is there at least one location on the moon where there are volcanic gases and materials presently being expelled or which exhibit a temperature anomaly sufficiently large to indicate possible active volcanism?

3.2 Are there internally generated seismic vibrations detectable at the surface of the moon?

3.3 What are the temperature gradients (horizontal and vertical) and thermal conductivities, as a function of depth below the surface, within the maria and highlands?

3.4 Where on the moon is the crust now being deformed as a result of tectonic processes (volcanism, quakes, folding, subsidence processes, etc.)?

3.5 What are the principal denudation processes now acting on the lunar surface?

3.6 Where are each of the tectonic processes (e.g., volcanism, quakes, folding, etc.) now occurring on the Moon? To what extent, and with what intensity are they occurring?

3.7 What gases are present in the lunar atmosphere? In what abundances are the principal ones present?

3.8 What are the internal sources of heat which produce heat flow (e.g., radioactivity, stress, hot core, igneous activity, etc.)?

3.9 What is the shape of the magnetic field on and around the moon, and how is it related to the interplanetary field?

4. HISTORY OF EVENTS

4.1 At the lunar surface what age periods are represented by the rock units (stratigraphic column)?

4.2 In samples of the lunar surface what magnetic fields are detectable?

4.3 Are there compounds on the lunar surface which are indicators of a biological evolution (e.g., ammonia, water, amino acids, proteins, etc.)?

4.4 Are there living organisms present on or beneath the lunar surface?

4.5 Are the land masses (e.g., maria and highlands) on the back side of the moon different in appearance, distribution and elevation as compared to those on the sub-Earth face which might indicate that the two sides may have different histories?

4.6 What principal processes are responsible for the present relief of the lunar surface (e.g., volcanism, impacting, folding, faulting, denudation, etc.)?

4.7 What is the best estimate of the moon's age based on the dating of materials?

4.8 Does the oldest exposed rock unit on the lunar surface represent material which was formed during the initial formation or cooling of the moon?

4.9 What has been the dynamical interaction between the moon and Earth,during and subsequent to their formation, as determined from tidal gravity, density distribution, departure from fluid equilibrium, and librations?

4.10 Do stratigraphic units, structural features, and heat flow of the moon indicate whether it is heating up or cooling down?

4.11 How have lunar tectonic processes (volcanism, folding, faulting, etc.), varied in location and activity during the past as determined from structural, topographic, and stratigraphic relationships, and the present tectonic pattern?

4.12 What has been the location and magnitude of volcanic activity during any period of lunar geologic time, as determined by stratigraphic units and structural features?

4.13 How has the number of impact craters varied with geologic time as determined from crater appearance and the relationship between foreign (meteoritic) and indigenous (lunar surface) materials?

4.14 What evidence is there on the moon of the influx of radiation from outer space in the past?

Table 2

QUESTION/INSTRUMENT RELATIONSHIPS FOR LUNAR ORBITERS

QUESTIONS / INSTRUMENTS	1** RADAR-ALTIMETER	2 X-RAY SPEC-TROMETER	3 SOLAR X-RAY MONITOR	4 VIDICON CAMERA	5 MULTI-SPEC. IMAGER	6 VIS-UV-SPEC-TROMETER	7 IR SPECTRO-METER	8 IR RADIOMETER (3-10μ)	9 IR-VIS-UV GAS SPECTROMETER	10 IR RADIOMETER (8-28μ)	11 QUADRUPOLE MASS SPEC.	12 REDHEAD PRESS. GAUGE	13 METRIC CAMERA
1. MASS DIST./BODY DENSITY													
1.1* Gravity Field+													
1.2 Major Discontinuities													
1.3 Local/Elev of Surface points+	X												
1.4 Mass Distribution+	X												
2. CHEMICAL/PHYSICAL PROPERTIES													
2.1 Chemical Element Variation		X	X	X									
2.2 Percentages of Elements		X	X	X									
2.3 Materials Distribution		X	X	X	X	X	X						
3. PROCESSES OF MOON													
3.1 Volcanic Processes								X	X				
3.2 Seismic Vibrations													
3.3 Thermal Properties													
3.4 Tectonic Processes										X			X
3.5 Denudation Processes													X
3.6 Location of Tectonic Proc.										X			X
3.7 Atmosphere Gases											X	X	
3.8 Sources of Heat Flow									X				X
3.9 Magnetic Field													

* Numbers correspond to interpreted SSB Question listed in Table 1.
**Numbers correspond to instrument/references listed in Table 3.
\+ Indicates those questions completely answered by orbital measurements.

Table 2 (Cont'd)

QUESTION/INSTRUMENT RELATIONSHIPS FOR LUNAR ORBITERS

QUESTIONS \ INSTRUMENTS	1** RADAR-ALTIMETER	2 X-RAY SPEC-TROMETER	3 SOLAR X-RAY MONITOR	4 VIDICON CAMERA	5 MULTI-SPEC. IMAGER	6 VIS-UV-SPEC-TROMETER	7 IR SPECTRO-METER	8 IR RADIOMETER (3-10μ)	9 IR-VIS-UV GAS SPECTROMETER	10 IR RADIOMETER (8-28μ)	11 QUADRUPOLE MASS SPEC.	12 REDHEAD PRESS. GAUGE	13 METRIC CAMERA
4. HISTORY OF EVENTS													
4.1* Stratigraphic Units		X	X	X	X	X	X						
4.2 Remnant Magnetism													
4.3 Organic and Protoorganic Material													
4.4 Living Organisms													
4.5 Morphology+													X
4.6 Processes responsible for Lunar Relief		X	X	X	X	X	X			X			X
4.7 Age of Moon		X	X	X	X	X	X						X
4.8 Primordial Material		X	X	X	X	X	X						X
4.9 History of Dynamic Interaction	X												
4.10 History of Thermal Regime		X	X	X	X	X	X			X			X
4.11 History of Tectonic Proc.		X	X	X	X	X	X			X			X
4.12 History of Volcanic Activity		X	X	X	X	X	X			X			X
4.13 History of Flux of Solid Objects		X	X	X	X	X	X			X			X
4.14 History of Flux of Radition		X	X	X	X	X	X						

*Numbers correspond to interpreted SSB question listed in Table 1.
**Numbers correspond to instrument/references listed in Table 3.
+Indicates those questions completely answered by orbital measurements.

by which the original questions were interpreted and by which these relationships were derived can be examined in detail in Section 3 and Appendix B.

There are 22 questions for which data can be obtained from lunar orbiter instruments. One other question which is applicable to lunar orbiter missions does not require specific instrumentation, but rather spacecraft tracking.

A total of 12 instruments plus a metric camera (which is being considered in a separate, parallel study at NASA-Langley) have been specified for obtaining the necessary measurements from orbital missions. The instruments specified in the report are considered to be adequate, in conjunction with surface measurements, for the acquisition of remotely-sensed data pertinent to 23 of the 30 questions. The remaining seven questions require data obtainable only from the lunar surface.

There are six basic measurement requirements which utilize the 12 specified orbital instruments (plus metric camera). They are:

(1) Geometric shape
(2) Chemical element variation
(3) Material distribution
(4) Active volcanism
(5) Tectonic processes
(6) Atmospheric gases

At the present time, the performance of many of the included instruments have not been conclusively demonstrated. Thus, the conclusions reached about these instruments may be somewhat optimistic. Three instruments which heretofore have been recommended for lunar orbiter missions - the radar imager, microwave spectrometer, and gamma ray spectrometer - have not been included. It is believed that the radar imager does not provide sufficient penetration to determine the near-surface lunar structure; the microwave spectrometer does not provide adequate subsurface temperature discrimination in order to determine heat flow; and the gamma ray spectrometer is not considered unambiguous enough to give reliable identification of the chemical elements. These judgments are open to review and criticism and have been made only to prevent redundancy in the suggested instrument payload. Clearly these instruments should be carried if they can be accommodated.

The reference numbers at the top of Table 2 correspond to the instruments listed in Table 3. Table 3 gives a more detailed description of the instrument and measurement requirements which are necessary to carry out what is considered a minimum program for acquiring data from LOB III missions. These same specifications in Table 3, also are given at the end of Section 3 in Tables 5 through 17. There, the instruments are presented separately for reference, with additional remarks about their applicability.

3. LUNAR EXPLORATION MEASUREMENT REQUIREMENTS

As stated previously, and as presented in Appendix A, the original 15 SSB scientific questions were restated as 30 single-purpose objectives. It was then necessary to take each

TABLE 3
SUMMARY OF S
LUNAR ORBITER BLOCK

Instrument	Purpose	Illum.	Ground Coverage (km^2)	Spec. Range	Spec. Res.	Interference	Meas. Interval (° in lat. & long.)	No. of Meas.	Data Format	Data Bits Per Measurement	Total No. of Bits	Orb
1. Radar Altimeter	Spacecraft Altitude	N/A	25	10cm	-	Generator of 10cm signals	3	5,000	Video Pulses	150	7.5×10^5	Low
2. X-Ray Spectrometer	Elemental Composition	Vert. ±30°	100	.7-12Å	.2Å	Susceptible to nuclear interference	5	2,000	Digital	300	6×10^5	Low
3. Solar X-Ray Monitor	Solar X-Ray Monitoring	N/A	N/A	.7-12Å	-	Susceptible to nuclear interference	N/A	2,000	Digital	8	1.6×10^4	Low
4. Vidicon Camera	Percentage Shadowing	Vert. ±30°	2500	Visible	-	None	5	2,000	Video Analog	10^5	2×10^8	Low
5. Multispectral Imager	Rock Unit Identification	Vert. ±30°	1600	.4-13μ	-	Radiation from S/C. Reflected insolation.	10	500	Analog Current	4×10^5	2×10^8	Low
6. VIS-UV Spectrometer	Rock Signatures	Vert. ±30°	80	1000-6000Å	10Å	Reflected insolation	10	500	Analog Current	10^5	5×10^7	Low
7. IR Spectrometer	Rock Signatures	Vert. ±30°	80	8-13μ	.1μ	Radiation from S/C. Reflected insolation.	10	500	Analog Current	10^4	5×10^6	Low
8. IR Radiometer (3-10μ)	Volcanic Temp. Detection	N/A	2.3	3-10μ	-	Reflected insolation S/C emissions	1 meas/sec	-	Analog (chopped)	10	Nominal	Low
9. IR-VIS-UV Gas Spectrum Analyzer	Volcanic Gas Analysis	Vert. ±60°	1/4 x 1° FOV	.29-61μ	-	S/C gaseous emissions. Reflected insolation.	1 meas/sec	-	DC Analog	10	Nominal	Low
10. IR Radiometer (8-28μ)	Thermal Mapping	Zero	100	8-28μ	-	Reflected insolation. S/C emissions.	1	6×10^4	Analog (chopped)	10	6×10^5	Low
11. Quadrupole Mass Spectrometer	Gas Analysis	N/A	N/A	1-50AMU	1AMU	S/C gaseous emissions	1 spec/10 sec	$\frac{2.6 \times 10^5}{\text{month}}$	Analog	250	$\frac{6.5 \times 10^7}{\text{month}}$	Hig
12. Redhead Pressure Gauge	Atmospheric Pressure	N/A	N/A	N/A	N/A	S/C gaseous emissions	1 meas/100 sec	$\frac{1.3 \times 10^5}{\text{month}}$	Analog	5	$\frac{1.3 \times 10^5}{\text{month}}$	Hig

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JGGESTED
III INSTRUMENTATION

it	Maximum Perilune of Orbit (km)	Minimum Incl. of Orbit	Pointing (vertical)	Pointing Accuracy	Life-time (days)	Weight (lbs.)	Power (watts)	Volume (ft.^{3})	Development Status	Must Groupings	Primary Question Answered	Other Question Which Utilizes Data
	200	45°	±5°	±1/2°	14	65	117	2	Within State of the Art	None	1.3	1.4, 4.9
	100	45°	±5°	±1/2°	28	18	2	1	Now being developed	2,3,4	2.1	2.2, 2.3, 4.1, 4.6, 4.7, 4.8, 4.10, 4.11, 4.12, 4.13, 4.14
	100	45°	At Sun	N/A	N/A	11	1	1	Within State of the Art	2,3,4	2.1	SAME AS NO. 2
	100	45°	±5°	±1/2°	28	10	10	1	300-800 line systems have flown	2,3,4	2.1	SAME AS NO. 2
	100	60°	±5°	±1/2°	28	80	13	2	Now being A/C flown	5,6,7	2.3	4.1, 4.6, 4.7, 4.8, 4.10, 4.11, 4.12, 4.13, 4.14
	100	60°	±5°	±1/2°	28	20	10	2	Within State of the Art	5,6,7	2.3	SAME AS NO. 5
	100	60°	±5°	±1/2°	28	60	55	4	A/C Models have flown	5,6,7	2.3	SAME AS NO. 5
	200	45°	±5°	±1/2°	N/A	25	12	1.5	A/C Models have flown	8,9	3.1	None
	200	45°	±5°	±1/2°	28	35	15	1.2	Laboratory Models Built	8,9	3.1	None
	100	60°	±5°	±1/2°	28	50	30	3	A/C Models have flown	None	3.4	3.6, 3.8, 4.6, 4.10, 4.11 4.12, 4.13,
h	As low as possible	45°	Direction of motion	±1/2°	N/A	12	10	1	A/C Models have flown	None	3.7	None
h	As low as possible	45°	Omni-directional	N/A	28	5	1	1	Within State of the Art	None	3.7	None

of these objectives and to define their purpose and interpret all the terms in the sense in which they were being used. In the light of this interpretation it was then possible to express each question in terms of measurable quantities, and thus provide a basis for the determination of spacecraft measurements. The results of this procedure are presented in detail for each of the questions in Appendix B.

3.1 Measurement Specifications

In Table 4 is a summary of the measurement and instrument requirements for the individual questions. The reference numbers in the right column refer to the Lunar Orbiter Block III instruments which are presented individually for reference, in Tables 5 through 17. Although metric mapping has been designated among the measurements, the derivation of the metric camera specifications has been specifically excluded from this study.

The procedure that was followed for designating the measurement requirements was by round table discussion and consensus of a group comprised of five scientist. In no case was a consensus easily established, and many hours of discussion were involved before decisions were made. This same group was responsible for designating the specifications for the required Lunar Orbiter Block III instruments covered in Section 3.2. It was assumed that spacecraft tracking would permit the location of the spacecraft to be determined at all times throughout a mission.

Table 4

SUMMARY OF MEASUREMENT REQUIREMENTS

Question No.	Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Reference No.*
1.1	Gravity field+	Track satellite perturbations	N/A	O	None
1.2	Internal structure (core, mantle, crust, or other rock units)	Seismometry	Passive seismometers	S	None
		Magnetometry (?)	Magnetometer	S	None
		Gravimetry	Gravimeter		
(Data obtained for 1.1 also applies to this question.)					
1.3	Surface point elevation+ & location with respect to center of mass	Altimetry	Radar altimeter	O	1
1.4	Mass distribution+	Uses same data as 1.1, 1.2, and 1.3.			
2.1	Element identification & abundance	X-ray signatures	X-ray spectrometer	O	2
			X-ray solar monitor	O	3
			Vidicon camera	O	4
			Surface solar wind flux	S	None
		Sample analysis	(Laboratory)	S	None
2.2	Percentages of elements	Uses same data as 2.1.			
2.3	Chemical composition	X-ray signatures	X-ray spectrometer	O	2
			X-ray solar monitor	O	3
			TV vidicon camera	O	4
			Surface solar wind flux	S	None
		Sample analysis	(Laboratory)	S	None
	Mineralogical composition	EM signatures	Multispectral imager	O	5
			UV-Vis spectrometer	O	6
			IR spectrometer	O	7
		Sample analysis	(Laboratory)	S	None
	Physical properties	Sample analysis	(Laboratory)	S	None
(Data obtained for 2.1 also applies to this question.)					

*Instrument reference numbers refer to listings in Tables 2, 3, and 5 through 17.
+Indicates those questions completely answered by orbital measurements.

Table 4 (Cont'd)

Question No.	Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Reference No.
3.1	Products of volcanism (molten material, gases, temp. anomalies)	Thermal mapping	IR radiometers	O	8
		Gas analysis	IR, vis, UV, gas spectrum analyzer	O	9
		Seismometry	Passive seismometers	S	None
3.2	Seismic vibrations	Surface measurements only			
3.3	Thermal properties	Surface measurements only			
3.4	Active areas	Seismometry	Passive seismometers	S	None
		Temperature mapping	IR radiometer	O	10
		Active seismometry	Active seismometers	S	None
	Rock structure	Topographic mapping	Med-Hi resolution cameras	O	13
		Surface geo. mapping	N/A	S	None
3.5	Denudation processes (slumping, solar wind, micrometeorite flux, etc.)	Sample analysis	(Laboratory)	S	None
		Environmental monitoring	Surface micrometeorite detector, plasma probe, & cosmic ray, etc.	S	None
		Surface topography	Med-Hi res. cameras	O	13
3.6	Location of tectonic processes	Uses same orbital data as 3.4 plus surface measurements			
3.7	Atmos. gases (neutral atoms, molecules, & ions)	Gas analysis	Mass spectrometer	O	11
		Pressure detection	Pressure gauge		
3.8	Sources of heat flow	Uses same orbital data as 1.2, 3.3, and 3.4 plus surface measurements			
3.9	Magnetic field	Surface measurements only			

Table 4 (Cont'd)

Question No.	Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Reference No.
4.1	Age of rock samples	Radioactive dating	(Laboratory)	S	None
	Rock unit distribution	EM signatures & spectra	X-ray spect., X-ray solar monitor, vidicon, multi-spect. imagers, IR spectrometer, UV-Vis spec.	O	2,3,4,5,6,7
	Rock unit relationship	Surface geo.mapping	N/A	S	None
		Photo mapping	Low-Med res. camera	O	13
4.2	Paleomagnetism	Sample analysis	(Laboratory)	S	None
4.3	Prebiological compounds	Sample analysis	(Laboratory)	S	None
4.4	Living organisms	Sample analysis	(Laboratory)	S	None
4.5	Land form types+	Topographic mapping	Low resolution camera	O	13
	Land mass elevation	Altimetry	Radar altimeter	O	1
4.6	Lunar relief Uses same orbital data as 2.3,3.4,3.5, and 3.6 plus surface measurements				
4.7	Age of moon Uses same orbital data as 2.3 plus surface measurements				
4.8	Primordial matter Uses same orbital data as 2.3 plus surface measurements				
4.9	Dynamic interaction Uses same orbital data as 1.1,1.2, and 1.3 plus surface measurements				
4.10	Thermal regime Uses same orbital data as 2.3,3.3, and 3.8 plus surface measurements				
4.11	Tectonic processes Uses same orbital data as 2.3 and 3.6 plus surface measurements				

+Indicates those questions completely answered by orbital measurements.

Table 4 (Cont'd)

Question No.	Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Reference No.
4.12	Volcanic activity				
		Uses same orbital data as 2.3 and 3.6 plus surface measurements			
4.13	Flux of solid objects				
		Uses same orbital data as 2.3,3.5, and 3.6 plus surface measurements			
4.14	Flux of radiation				
		Uses same orbital data as 2.3 plus surface measurements			

3.2 Instrument Specifications

The last phase of the study required that the Lunar Orbiter Block III instrument requirements be specified in as much detail as possible. However, as these specifications were being generated, it became very difficult to avoid making some decisions which properly should be part of the Phase A study. For instance, although some instruments seem to fall into an automatic scientific grouping (as for example, instruments for remote chemical and remote mineralogical analysis), it is not justifiable to group them into a single package. Such groupings must be determined by the data handling and transmission problems, weight, pointing, etc., as well as the scientific objectives.

On the other hand, it has been imperative that certain instruments be flown and operated together, if any useful purpose is to be served. The three cases where this has been found to apply are:

(1) The X-ray spectrometer, the X-ray solar monitor, and the vidicon camera must fly together for the determination of elemental abundances.

(2) The multispectral imager, the IR spectrometer, the vis/UV spectrometer must fly together for identifying rock types.

(3) The threshold gas analyzer and the threshold IR radiometer must fly together for the detection of active volcanism.

In order to minimize the conceptual design decisions which might creep into the instrument specifications, no payload groupings have been attempted except where they are scientifically essential, as noted above. The philosophy has been adopted that Block III orbiters should be designed to accomplish all of the applicable questions for lunar exploration. Therefore, all of the measurement requirements have been developed independently, and the derivation of the most suitable payload groupings has been properly deferred for the Phase A study.

The mechanism used for determining the instrument specifications was by the consensus of a group of five scientists. As the first step, a list was made of all instruments, with specifications, which could be gleaned from the literature.

The selected specifications are:

Illumination

Limits are established for the direction of illumination, with respect to the subsolar point. The major illumination constraint for remote sensing is provision of adequate insolation to excite a high percentage of the surface area.

Ground Coverage

This is specified as a field of view and resolution coverage on the lunar surface. The required instrumental angular field of view and resolution will then depend on the altitude of the spacecraft. In general, the required ground coverage is not too critical.

Spectral Range and Resolution

These ranges are provided where necessary, on a scientific basis. The data requirements have not generally been allowed to constrain these spectral specifications.

Measurement Interval

This refers to the lunar latitudes and longitudes at which measurements are required. In many cases a measurement grid has been specified over the entire lunar surface.

Number of Measurements

This is the total number of measurements as derived from the above interval requirements. In all cases, it represents the minimum number which can fulfill the objectives. No contingency has been allowed for imperfect measurements.

Data Format

Wherever possible, no data handling or recording equipment has been included with the instrument. This is to allow the Phase A considerations to be freely applied. The instrument weight as given below provides only for the stated output data format.

Bits Per Measurement

These are derived on the basis of the required ground coverage, resolution, the spectral range, and resolution.

Total Bits

For each instrument, the minimum total bits are specified as the product of the minimum number of measurements and the bits per measurement. No contingency is allowed. Consideration has been given to the scientific requirement for data film return to the Earth. In no case could a scientific requirement be clearly isolated.

Orbital Parameters

The specified orbital parameters are limited to eccentricity, perilune, and inclination. In general, circular orbits are preferred but are not essential. Similarly, the perilune should be as low as possible, and polar orbits are preferred.

Pointing

The direction and accuracy of the pointing requirements are specified for each instrument. Due to the general large-scale surveillance objectives of Lunar Orbiter Block III, the pointing requirements are not stringent.

Lifetime

This is the minimum lifetime which will be required for the spacecraft to provide the stated number of measurements under the appropriate lighting conditions. No contingency has been allowed.

Interference

A note is made of any interference to which the instrument is susceptible, or which it generates.

Weight, Power, and Volume

These physical specifications are "best guesses" for instruments meeting all of the above specifications.

Development Status

It is expected that all of the instruments listed in this report will be available for Lunar Orbiter Block III missions. The instruments which have been included with most reservations, are those which are to provide IR, visible, and UV signatures of rock types.

Table 5

1 - RADAR ALTIMETER (10 cm)

Purpose: Altitude of Spacecraft with Respect to Surface
Primary Question: 1.3
Other Questions Which Utilize Data: 1.4, 4.9

Specifications	Value	Remarks
Illumination	N/A	
Ground coverage	25 km^2	Approximately 3° beamwidth antenna is assumed.
Spectral range	10 cm	
Spectral resolution	-	The wavelength of the transmitted signal is fixed.
Interference	Generator of 10 cm signals	12 kw of peak power are generated.
Measurement interval	3° in lat. and long.	This is compatible with gravity requirements.
No. of measurements	5,000	
Data format	Video pulses	No recorder is included.
Data bits/measurement	150	
Total number of bits	7.5×10^5	
Orbit eccentricity	Low	Circular orbit preferred.
Perilune	200 km	
Inclination of orbit	45°	Polar orbit is preferred.
Pointing	Vertical $\pm$ 5°	
Pointing accuracy	$\pm$ 1/2°	
Lifetime	14 days	
Weight (lb)	65	This weight includes 2.6 ft antenna.
Power (watts)	110	
Volume (ft^3)	2	
Development status	Within the state-of-the-art	

General Comments:

- 10-20 m. altitude accuracy is attainable.
- Spacecraft tracking is necessary to locate the position of the spacecraft with respect to the lunar center of mass.

Table 6

2 - X-RAY SPECTROMETER

Purpose: Element Identification and Abundances
Primary Question: 2.1
Other Questions Which Utilize Data: 2.2, 2.3, 4.1, 4.6, 4.7, 4.8, 4.10, 4.11, 4.12, 4.13, 4.14

Specifications	Value	Remarks
Illumination	Vertical $\pm$ 30°	This is to insure adequate insolation.
Ground coverage	100 km^2	Measurement is averaged over 100 km^2.
Spectral range	.7-12 Å	
Spectral resolution	.2 Å	
Interference	Susceptible to nuclear interference	
Measurement interval	5° in lat. and long.	
No. of measurements	2,000	
Data format	Digital	Data is in form of digital output from pulse height analyzer.
Data bits/measurement	300	
Total number of bits	6×10^5	300 bits needed for 60 channel spectrum.
Orbit eccentricity	Low	
Perilune of orbit	$\leq$ 100 km	Low as possible is desired to improve S/N ratio.
Inclination of orbit	$\geq$ 45°	Polar orbit is preferred.
Pointing	Vertical $\pm$ 5°	
Pointing accuracy	$\pm$ 1/2°	
Lifetime	$\geq$ 28 days	There is a 60 day maximum period every 6 months due to lighting constraint.
Weight (lb)	18	This weight includes pulse height analyzer.
Power (watts)	2	
Volume (ft^3)	1	
Development status	Now being developed	Expected to be available for LOB III.

General Comments:

- For scientific purposes, this instrument must fly with instruments 3 and 4.
- Should be bore-sighted with instrument 4.

Table 7

3 - SOLAR X-RAY MONITOR (ION CHAMBER)

Purpose: Monitor Solar X-ray Flux
Primary Question: 2.1
Other Questions Which Utilize Data: 2.2, 2.3, 4.1, 4.6, 4.7, 4.8, 4.10, 4.11, 4.12, 4.13, 4.14

Specifications	Value	Remarks
Illumination	N/A	The instrument looks at the Sun.
Ground coverage	N/A	
Spectral range	.7-12 Å	High energy range preferred but not critical.
Spectral resolution	-	
Interference	Susceptible to nuclear interference	
Measurement interval	N/A	
No. of measurements	2,000	
Data format	Digital	
Data bits/measurement	8	
Total number of bits	1.6×10^4	
Orbit eccentricity	Low	These requirements are determined by X-ray spectrometer.
Perilune of orbit	$\leq$ 100 km	
Inclination of orbit	$\geq$ 45°	
Pointing	At Sun	
Pointing accuracy	N/A	
Lifetime	N/A	Lifetime is determined by X-ray spectrometer.
Weight (lb)	11	
Power (watts)	1	
Volume (ft^3)	1	
Development status	Ion chambers have flown on OGO & OSO	8-20 Å ion chamber flew on OSO-C.

General Comments:

- For scientific purposes this instrument must fly with instruments 2 and 4.

Table 8

4 - VIDICON CAMERA

Purpose: To give Percent of Measured Area Illuminated.
Primary Question: 2.1
Other Questions Which Utilize Data: 2.2, 2.3, 4.1, 4.6, 4.7, 4.18, 4.10, 4.11, 4.12, 4.13, 4.14

Specifications	Value	Remarks
Illumination	Vertical $\pm$ 30°	This is determined by X-ray spectrometer.
Ground coverage	2500 km^2	
Spectral range	Visible	200 line system (4 x 10^4 res.elements/pic) with 8 shades of gray.
Spectral resolution	-	
Interference	None	
Measurement interval	5° in lat. and long.	
No. of measurements	2,000	
Data format	Video analog	No storage is included.
Data bits/measurement	10^5	
Total number of bits	2 x 10^8	
Orbit eccentricity	Low	
Perilune of orbit	$\leq$ 100 km	
Inclination of orbit	$\geq$ 45°	
Pointing	Vertical $\pm$ 5°	
Pointing accuracy	$\pm$ 1/2°	
Lifetime	28 days	There is 60 days maximum period every 6 months (lighting).
Weight (lb)	10	
Power (watts)	10	
Volume (ft^3)	1	
Development status	300-800 line systems have flown	No data on specific instruments available

General Comments:

- For scientific purposes, this instrument must fly with instruments 2 and 3.
- Camera is necessary to show percentage of shadowing in area measured by instrument 2.
- Should be bore-sighted with instrument 2.

Table 9

5 - MULTISPECTRAL IMAGER

Purpose: Identification of Rock Units
Primary Question: 2.3
Other Questions Which Utilize Data: 4.1, 4.6, 4.7, 4.8, 4.10, 4.11, 4.12, 4.13, 4.14

Specifications	Value	Remarks
Illumination	Vertical $\pm$ 30°	This provides adequate insolation.
Ground coverage	40 x 40 km	
Spectral range	.40-13μ	System consists of resolution elements of .3 km x .3 km with 16 levels of gray. The 5 channels are: .40-.45μ, .65-.70μ, .8-1.3μ, 2.0-2.4μ, and 8-13μ.
Spectral resolution	-	
Interference	Radiation from S/C reflected insolation	
Measurement interval	10° in lat. and long.	
No. of measurements	500	
Data format	Analog current	Very fast response time is required
Data bits/measurement	4 x 10^5	
Total number of bits	2 x 10^8	
Orbit eccentricity	Low	
Perilune of orbit	$\leq$ 100 km	
Inclination of orbit	$\geq$ 60°	Polar orbit is preferred.
Pointing	Vertical $\pm$ 5°	
Pointing accuracy	$\pm$ 1/2°	
Lifetime	28 days	There is a 60 day maximum period every 6 months (lighting).
Weight (lb)	80	This weight includes cryogenics
Power (watts)	13	
Volume (ft^3)	2	
Development status	Now being A/C flown	

General Comments:

- For scientific purposes this instrument must fly with instruments 6 and 7.

Table 10

6 - VISIBLE UV SPECTROMETER

Purpose: Rock Signatures
Primary Question: 2.3
Other Questions Which Utilize Data: 4.1, 4.6, 4.7, 4.8, 4.10 to 4.14

Specifications	Value	Remarks
Illumination	Vertical $\pm$ 30°	Coordinated with multispectral imager.
Ground coverage	2 x 40 km*	
Spectral range	1000-6000 Å	Each spectra covers 2 x 2 km. 20 of them are taken in succession at the rate of 1/sec.
Spectral resolution	10 Å	
Interference	Reflected insolation	
Measurement interval	10° in lat. and long.	Coordinated with multispectral imager.
No. of measurements	500	
Data format	Analog current	
Data bits/measurement	10^5	
Total number of bits	5×10^7	
Orbit eccentricity	Low	
Perilune of orbit	$\leq$ 100 km	Low as possible is desired to improve S/N ratio.
Inclination of orbit	$\geq$ 60°	
Pointing	Vertical $\pm$ 5°	Polar orbit is preferred.
Pointing accuracy	$\pm$ 1/2°	
Lifetime	28 days	There is a 60 day maximum period every 6 months (lighting).
Weight (lb)	20	
Power (watts)	10	
Volume (ft^3)	2	
Development status	Within state of the art	No information on specific instrument.

*The measured area should be a strip down the center of the area measured by the multi-spectral imager.

General Comments:

- For scientific purposes, this instrument must fly with instruments 5 and 7.
- Should be bore-sighted with instruments.

Table 11

7 - IR SPECTROMETER

Purpose: Rock Signatures
Primary Question: 2.3
Other Questions Which Utilize Data: 4.1, 4.6, 4.7, 4.8, 4.10 to 4.14

Specifications	Value	Remarks
Illumination	Vertical $\pm$ 30°	Coordinated with multispectral imager.
Ground coverage	2 x 40 km*	
Spectral range	8-13μ	
Spectral resolution	.1μ	
Interference	IR radiation from S/C reflected insolation	
Measurement interval	10° in lat. & long.	Coordinated with multispectral imager.
No. of measurements	500	
Data format	Analog current	
Data bits/measurement	10^4	
Total number of bits	5×10^6	
Orbit eccentricity	Low	
Perilune of orbit	$\leq$ 100 km	Low as possible is desired in order to increase S/N ratio.
Inclination of orbit	$\geq$ 60°	
Pointing	Vertical $\pm$ 5°	Polar orbit is preferred.
Pointing accuracy	$\pm$ 1/2°	
Lifetime	28 days	There is a 60 day maximum period every 6 months (lighting).
Weight (lb)	60	This weight includes cryogenics.
Power (watts)	55	
Volume (ft^3)	4	
Development status	A/C models have flown	

*The measured area should be a strip down the center of the area measured by the multispectral imager.

General comments:

- For scientific purposes, this instrument must fly with instruments 5 and 6.
- Should be bore-sighted with instrument 6.

Table 12

8 - IR RADIOMETER (3-10μ)

Purpose: Detection of Temperatures Which Indicate Active Volcanism
Primary Question: 3.1
Other Questions Which Utilize Data: None

Specifications	Value	Remarks
Illumination	N/A	
Ground coverage	2.5 km^2	Size of average Earth volcano - image motion compensation is not necessary.
Spectral range	3-10μ	
Spectral resolution	-	
Interference	Reflected insolation spacecraft emissions	
Measurement interval	1 meas/sec	Measurements are continuous throughout orbit.
No. of measurements	-	
Data format	Analog (chopped)	Temperature is read out above a threshold of 500°C.
Data bits/measurement	10	
Total number of bits	Nominal	
Orbit eccentricity	Low	
Perilune of orbit	≤ 200 km	
Inclination of orbit	≥ 45°	Polar orbit is preferred.
Pointing	Vertical ± 5°	
Pointing accuracy	± 1/2°	
Lifetime	N/A	
Weight (lb)	25	
Power (watts)	12	
Volume (ft^3)	1.5	
Development status	A/C models have flown	

General Comments:

- For scientific purposes this instrument must fly with instrument 9 and should be in every payload.

Table 13

9 - UV VISIBLE IR GAS SPECTRUM ANALYZER

Purpose: Gas Detection from Active Volcanism
Primary Question: 3.1
Other Questions Which Utilize Data: None

Specifications	Value	Remarks
Illumination	Vertical ± 60°	This provides adequate gas excitation.
Ground coverage	1/4° x 1° FOV	Not observing ground phenoma. Instrument is calibrated for specific gases (i.e., SO_2)
Spectral range	.29-.61μ	
Spectral resolution	-	
Interference	Reflected insolation S/C gaseous emissions	
Measurement interval	1 sample/sec	Continuous measurements are made on light-side.
No. of measurements	-	
Data format	DC analog	Gas concentration is read out above a threshold of 10^8 molecules/cc.
Data bits/measurement	10	
Total number of bits	Nominal	
Orbit eccentricity	Low	
Perilune of orbit	≤ 200 km	
Inclination of orbit	≥ 45°	Polar orbit is preferred.
Pointing	Vertical ± 5°	
Pointing accuracy	± 1/2°	
Lifetime	28 days	120 day maximum period approximately every 6 months (lighting).
Weight (lb)	35	
Power (watts)	15	
Volume (ft^3)	1.2	
Development status	Lab models built	Available for LOB III

General Comments:

- For scientific purposes this instrument must fly with instrument 8, and should be in every payload.

Table 14

10 - IR RADIOMETER (8-28μ)

Purpose: Thermal Mapping for Tectonic Activity
Primary Question: 3.4
Other Questions Which Utilize Data: 3.6, 3.8, 4.6, 4.10 to 4.13

Specifications	Value	
Illumination	Zero	Measurements should be taken between anti-solar long. & that longitude +30°* (see general comments).
Ground coverage	100 km^2	
Spectral range	8-28μ	
Spectral resolution	-	
Interference	Reflected insolation spacecraft emissions	
Measurement interval	1° in lat. and long.	
No. of measurements	6×10^4	
Data format	Analog (chopped)	
Data bits/measurement	10	
Total number of bits	6×10^5	
Orbit eccentricity	Low	As low as possible.
Perilune of orbit	$\leq$ 100 km	Low altitude necessary to improve S/N ratio.
Inclination of orbit	$\geq$ 60°	
Pointing	Vertical $\pm$ 5°	
Pointing accuracy	$\pm$ 1/2°	
Lifetime	$\overline{3}$0 day (min. after reaching anti-solar long.)	Because of cryogenic storage problem, anti-solar longitude should be reached as soon as possible.
Weight (lb)	50	Weight includes cryogenics.
Power (watts)	30	
Volume (ft^3)	3	
Development status	A/C models have flown	

*Darkside measurements are required in order to provide for suppression of diurnal effect. Thermal maps should be correlated with metric maps.

General comments:

- Instrument is capable of measuring down to 100°K.

Table 15

11 - QUADRUPOLE MASS SPECTROMETER

Purpose: Lunar Atmospheric Gas Detection
Primary Question: 3.7
Other Questions Which Utilize Data: None

Specifications	Value	Remarks
Illumination	N/A	Approximate knowledge of solar illumination is needed.
Ground coverage	N/A	
Spectral range	1-50 AMU	
Spectral resolution	1 AMU	
Interference	S/C gaseous emissions	Instrument is extremely sensitive to gaseous emissions.
Measurement interval	1 spectrum/10 sec	Measurements are made alternately on ions and neutral particles.
No. of measurements	2.6×10^5/month	
Data format	Analog	
Data bits/measurement	250	
Total number of bits	6.5×10^7/month	
Orbit eccentricity	High	High eccentricity is preferred but not critical.
Perilune of orbit	As low as possible	
Inclination of orbit	$\geq 45°$	
Pointing	Direction of motion	
Pointing accuracy	$\pm 1/2°$	
Lifetime	N/A	
Weight (lb)	12	
Power (watts)	10	
Volume (ft^3)	1	
Development status	A/C models have flown	No data on specific instrument specified.

General Comments:

- For scientific purposes, this instrument should fly in every payload.

Table 16

12 - REDHEAD PRESSURE GAGE

Purpose: Measurement of Lunar Atmospheric Pressure
Primary Question: 3.7
Other Questions Which Utilize Data: None

Specifications	Value	Remarks
Illumination	N/A	Approximate knowledge of illumination is necessary.
Ground coverage	N/A	
Spectral range	N/A	
Spectral resolution	N/A	
Interference	Spacecraft gaseous emissions	Extremely sensitive to spacecraft outgassing.
Measurement interval	1 meas/100 seconds	
No. of measurements	2.6×10^4/month	
Data format	Analog	
Data bits/measurement	5	
Total number of bits	1.3×10^5/month	
Orbit eccentricity	High	(Not critical.)
Perilune of orbit	As low as possible	
Inclination of orbit	$\geq 45°$	
Pointing	Omni-directional	
Pointing accuracy	N/A	
Lifetime	28 days	
Weight (lb)	5	
Power (watts)	1	
Volume (ft^3)	1	
Development status	Within the state-of-the-art	

General Comments:

- For scientific purposes, this instrument should fly in every payload.

Table 17

13 - METRIC CAMERA

Purpose: Photographic Mapping
Primary Question: None
Other Questions Which Utilize Data: 2.3, 3.4, 3.5, 3.6, 3.8, 4.1, 4.5, 4.6, 4.7, 4.8, 4.10, 4.11, 4.12, 4.13

Specifications	Value	Remarks
Illumination		Specifications to be supplied by Langley Research Center.
Ground coverage		
Spectral range		
Spectral resolution		
Interference		
Measurement interval		
No. of measurements		
Data format		
Data bits/measurement		
Total number of bits		
Orbit eccentricity		
Perilune of orbit		
Inclination of orbit		
Pointing		
Pointing accuracy		
Lifetime		
Weight (lb)		
Power (watts)		
Volume (ft^3)		
Development status		

General Comments:

- Only remote sensing has been included under the terms of this study. However, where there has been an application of correlating remote sensing data with photo data, it has been indicated.

4. CONCLUSIONS

One of the conclusions derived from this study is that orbital measurements will provide useful data in helping to answer some questions about the moon; for assisting in mapping the lunar surface; and possibly, to a limited extent, mapping the subsurface. Also, it appears reasonable to judge that, for the most part, the orbital data will be limited to reconnaissance (i.e., locating suitable landing sites as well as interesting surface areas for investigation), and for obtaining gross data to facilitate the extrapolation and correlation of surface data from one surface area to another.

Consequently, the orbital data is considered to be primarily supplementary to surface data. Most of the lunar exploration questions only can be fully answered by extensive surface exploration. However, since surface missions are not likely to be numerous or extensive enough in scope to give adequate coverage of the surface, a combination of the two types of missions - orbital and surface- is essential to provide an optimum program of lunar exploration.

This study has shown specific applications for remote sensing instruments which will be compatible with Block III type missions. These instruments have been specified in sufficient detail to be used as a direct input to a Phase A mission study. The relationship between the measurements and instruments is summarized in Table 18.

Table 18

MEASUREMENT/INSTRUMENT/QUESTION RELATIONSHIPS FOR LOB III

Measurement Requirements	LOB III Instruments	Instrument Purpose	Applicable Questions
Geometric shape	1. Radar altimeter	Spacecraft altitude	1.3,1.4,4.9
Chemical elemental variation	2. X-ray spec.	Elemental composition	2.1,2.2,2.3,4.1,4.6,4.7,4.8,4.10,4.11,4.12,4.13,4.14
	3. Solar X-ray monitor	Solar X-ray monitoring	N/A Supports X-ray spec.
	4. Vidicon camera	Percentage shadowing (in conjunction with X-ray spectrometer)	N/A Supports X-ray spec.
(Surface measurements are also necessary.)			
Material distribution*	2,3,4	Same as above	
	5. Multispectral imager	Rock unit identification	2.3,4.1,4.6,4.7,4.8,4.10,4.11,4.12,4.13,4.14
	6. Vis-UV spectrometer	Rock signatures	2.3,4.1,4.6,4.7,4.8,4.10,4.11,4.12,4.13,4.14
	7. IR spectrometer	Rock signatures	2.3,4.1,4.6,4.7,4.8,4.10,4.11,4.12,4.13,4.14
(Surface measurements are also necessary.)			
Active volcanism	8. IR radiometer (3-10μ)	Volcanic temperature detection	3.1
	9. IR-Vis-UV gas spectrum analyzer	Volcanic gas analysis	3.1

Table 18 (Cont'd)

Measurement Requirements	LOB III Instruments	Instrument Purpose	Applicable Questions
Tectonic processes*	10. IR radiometer (8-28μ)	Thermal mapping	3.4,3.8,4.6,4.10,4.11,
(Surface measurements are also necessary.)			
Atmospheric gases	11. Quadrupole mass spectrometer	Gas analysis	3.7
	12. Redhead pressure gauge	Atmospheric pressure	3.7

*Metric camera (photographic mapping) is necessary.

REFERENCES

Falmouth 1965, Summer Conference on Lunar Exploration and Science, NASA SP-88 (July 1965).

NASA 1966, Lunar Exploration Working Group of NASA, "Lunar Exploration Program Plan" (November 1966).

SSB 1965, Space Research - Directions for the Future: Planetary and Lunar Exploration. Space Science Board of National Academy of Sciences (December 1965).

BIBLIOGRAPHY

Advanced Mission Division, NASA Headquarters, "Manned Lunar Orbital Missions," Volume 1A (April 1965).

Astro Sciences Center, IIT Research Institute, "Preliminary Outline of a Planning Methodology for Total Lunar Exploration" (May 1966).

Beckman, W. A. and Whitten, E. H., Geology Department, Northwestern University, "Statistical Problems Involved in Remote Sensing of the Geology of the Lithosphere-Atmosphere Interface, J. of Geophys. Research, Vol. 71, 24 (December 15, 1966).

Bendix Corporation, "Apollo Logistics Support System Scientific Mission Support Study" (December 1964).

Bendix Corporation, "Scientific Mission Support Study Apollo Extension System" BSR-1153 (July 1965).

Boeing Company, "A Study of the Lunar Orbiter Regarding its Adaptability to Experiments to Evaluate Lunar Surface Characteristics," L-6753 (September 1966).

Brereton, R. B., "Scientific Instruments for Lunar Exploration," EPD-472, Part A - Lunar Orbiter (Unmanned) (January 1967).

Collins, R. J., University of Minnesota, and Smith, B.G. Bellcomm, Inc., "Crater Statistics and Erosion," AAS 66-183 (December 1966).

Earth Resources Infrared Team, "Earth Orbital Infrared" (January 1966).

Green, J., "Geophysics as Applied to Lunar Exploration," AFCRI TR-60-409, North American Aviation, Inc. (June 1960).

Hagfots, T., "Radar Properties of the Moon," Lincoln Laboratory, MIT (December 1966).

Hopfield, J. J., "Optical Properties and Infrared Emission of the Moon," Department of Physics, Princeton University (1966).

Jet Propulsion Laboratory, "Lunar Exploration Program Study," (working papers contributed by JPL to NASA), (January 1967).

Kaula, W., "The Geometric and Dynamical Figure of the Moon," University of California, AAS 66-189 (December 1966).

Kitchens, M. D., and Bristow, R. B., "Advanced Lunar Mission Capabilities," Advanced Technology Spacecraft Division, NASA MSC.

Kovach, R. L., "Lunar Seismic Exploration," Department of Geophysics, Stanford University, presented at the meeting of the American Association for the Advancement of Science, Washington, D. C. (December 1966).

Langley Research Center, "Status Report, Lunar Orbiter Block III Study" (October 1966).

Lockheed Missile and Space Company, "Lunar Orbital Survey Missions (LOSM)," NAS9-5288, Volume 3 (January 1967).

Orth, J. E., "Space Applications Sensors," IIT Research Institute Report PM-6 (February 1967).

BIBLIOGRAPHY (Cont'd)

Piotrowski, W. L. and Sables, B. E., "Lunar Orbital Experiments with the Apollo Mapping and Survey System," Case 600-4, Bellcomm, Inc. (January 1967).

Rowan, L. C., "Orbital Observations of the Lunar Surface," USGS, AAS 66-180 (December 1966).

Saari, J. M. and Shorthill, R. W., "Review of Lunar Infrared Observations," Boeing Scientific Research Laboratories, AAS 66-184 (December 1966).

Scoggins, W. H., "A Geological Analysis for Lunar Exploration," Astro Sciences Center of IIT Research Institute Report P-17 (1966).

Watts, H., "Reflectance of Rocks and Minerals to Visible and Ultraviolet Radiation," Astro Sciences Center of IIT Research Institute Report W6137-1 (April 1966).

Weber, A. H., Internal Note R-RP-INJ-64-21, NASA-MSFC (September 1964).

Appendix A

BASIC LUNAR SCIENTIFIC QUESTIONS

Appendix A

BASIC LUNAR SCIENTIFIC QUESTIONS

The 15 scientific questions of lunar exploration posed by the SSB are given in Table A1. These have been used as the starting point for the current study. The questions are grouped under the following original three categories:

(1) Structure and Processes of the Lunar Interior

(2) Composition, Structure, and Processes of the Lunar Surface, and

(3) History of the Moon.

For the purpose of this study, these original questions have been subdivided into 30 single-purpose questions, and re-grouped under four new categories. This arrangement provides a more logical ordering for the planning of lunar exploration. The four new categories are:

(1) Mass Distribution and Body Density of the Moon

(2) Chemical and Physical Properties of Lunar Surface Materials

(3) Processes of the Moon

(4) History of Lunar Events.

These categories and the scientific questions within each category have been listed in Table A2, but the list does not imply a rank order of importance or priority for investigation of the scientific questions.

Table A1

ORIGINAL SSB QUESTIONS

Category	Scientific Question
Structure and Processes of the Lunar Interior	Is the internal structure of the moon radially symmetrical like the earth, and if so, is it differentiated? Specifically, does it have a core and does it have a crust?
	What is the geometric shape of the moon? How does the shape depart from fluid equilibrium? Is there a fundamental difference in morphology and history between the sub-earth and averted faces of the moon?
	What is the present internal energy regime of the moon? Specifically, what is the present heat flow at the lunar surface and what are the sources of this heat? Is the moon seismically active and is there active volcanism? Does the moon have an internally produced magnetic field?
Composition, Structure, and Processes of the Lunar Surface	What is the average composition of the rocks at the surface of the moon and how does the composition vary from place to place? Are volcanic rocks present on the surface of the moon?
	What are the principal processes responsible for the present relief of the lunar surface?
	What is the present tectonic pattern on the Moon and distribution of tectonic activity?
	What are the dominant processes of erosion, transport, and deposition of material on the lunar surface?
	What volatile substances are present on or near the surface of the moon or in a transitory lunar atmosphere?
	Is there evidence for organic or proto-organic materials on or near the lunar surface? Are living organisms present beneath the surface?

Table A1 (Cont'd)

Category	Scientific Question
History of the Moon	What is the age of the moon? What is the range of age of the stratigraphic units on the lunar surface and what is the age of the oldest exposed material? Is a primordial surface exposed?
	What is the history of dynamical interaction between the Earth and the moon?
	What is the thermal history of the moon? What has been the distribution of tectonic and possible volcanic activity in time?
	What has been the flux of solid objects striking the lunar surface in the past and how has it varied with time?
	What has been the flux of cosmic radiation and high-energy solar radiation over the history of the Moon?
	What past magnetic fields may be recorded in the rocks at the moon's surface?

Table A2

SINGLE PURPOSE SSB QUESTIONS

Table A2 (Cont'd)

Table A2 (Cont'd)

Appendix B

DEVELOPMENT OF MEASUREMENT REQUIREMENTS

Appendix B

DEVELOPMENT OF MEASUREMENT REQUIREMENTS

In this study each of these 30 single questions listed in Appendix A in turn have been restated in relation to the measurements that must be made of the moon. The key measurement parameters and techniques have been developed, and an assessment has been made as to whether the techniques are best suited to orbital or surface exploration, or both. The development of the measurement requirements is provided in detail for each question in the following pages.

Question 1.1

SSB QUESTION

Is the internal structure of the moon radially symmetric?

Purpose of Question

To give information on the moon's interior and development, and to lead to a better understanding of the origin of the moon.

Question Considered in Terms of Measurable Quantities

What is the intensity of the gravitational field about the moon with respect to its center of mass?

Definition of Terms

Internal Structure - Material changes within the moon below the disturbed near-surface region, which separates the interior into distinct major rock units such as a core, mantle, and crust.

Radially Symmetric - Uniform distribution of materials about the center of mass.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.*
Gravitational field	Tracking satellite perturbations	N/A	O	None

- Satellite tracking with DSN** with current accuracy capability
- Several high inclinations or one polar orbit required for better than seventy percent coverage.
- Satellite lifetime of several months is required for measurement accuracy consistent with desired results.
- The tracking is assumed to be accomplished by Earth tracking stations.

*Instrument reference numbers refer to the listings in Tables 2, 3, and 5 through 17.

**Deep Space Network.

Question 1.2

SSB QUESTION

What is the internal structure of the moon?

Purpose of Question

A knowledge of the internal structure (particularly the core) is of primary importance for understanding its early evolutionary development and its relation to the Earth.

Question Considered in Terms of Measurable Quantities

What are the depths and shapes of major discontinuities within the moon?

Definition of Terms

Internal Structure - See Question 1.1 for definition

Major Rock Units - A rock unit which is essentially uniform in gross chemical and physical properties.

Major Discontinuities - A term used to describe boundaries or breaks between major rock units.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Internal structure (core, mantle, crust, or other rock units)	Seismometry	Passive seismometers	S	None
	Magnetometry(?)	Magnetometer	S	None
	Tidal gravimetry	Tidal gravimeter	S	None

- A gravity gradiometer would possibly contribute some information to this question, however, the gravity determination from orbital tracking is assumed to be adequate.

- Radar techniques do not provide penetration below the disturbed crustal region ($\sim$10 km).

Question 1.3

SSB QUESTION

What is the geometric shape of the moon?

Purpose of Question

To establish a mathematical surface for the moon with respect to its true shape. This is important in order to facilitate the establishment of a selenocentric coordinate system, a reference figure with respect to a center of mass, a three-dimensional geodetic control system in terms of latitude, longitude, and elevation, and for comparison with the gravitational equipotential surface.

Question Interpretation in Terms of Measurable Quantities

What are the relative locations and elevations of a specified number of different points of the lunar surface?

Definition of Terms

Geometric Shape - The imaginary mathematical surface which conforms to the average surface configuration of the moon.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Surface point elevation and location with respect to center of mass	Altimetry	Radar altimeter	O	1

Question 1.4

SSB QUESTION

How does the moon's shape depart from fluid equilibrium?

Purpose of Question

To determine if the moon behaves like a fluid; is rigid but in fluid equilibrium; or, is rigid but not in fluid equilibrium with its present environment.

Question Interpretation in Terms of Measurable Quantities

What is the mass distribution of the moon with regard to its shape, present tidal effect, and rigidity?

Definition of Terms

Fluid Equilibrium - The geometrical shape commensurate with the Earth-moon and Sun-moon tidal forces.

Tidal Effect - The effect on a planetary body due to the persistent gravitational attraction between two or more bodies.

Geometric Shape - See Question 1.3 for definition.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Geometric shape	Altimeter Satellite Tracking	Radar altimeter	O	1
Elasticity & rigidity	Tidal gravimetry Seismometry	Tidal gravimeter Passive seismometer	S S	None None
Mass distribution	Satellite tracking	N/A	O	None

Question 2.1

SSB QUESTION

How does the composition of the lunar surface vary from place to place?

Purpose of Question

The detection of variations in composition will permit classification of distinct areas as to possible processes responsible for their development and modification during geologic time. Using volcanism and meteoritic impact as examples, regional composition should vary inversely with the frequency of impact, the size of impacts, and amount of past volcanic activity.

Question Interpretation in Terms of Measurable Quantities

Do the most abundant elements (e.g., silicon, magnesium, oxygen, iron, etc.) vary on the order of $\pm$ 10 percent from mare to mare, highland to highland, from mare to highland, and regionally ($\sim$100 miles) within these areas?

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instrument	Orbit or Surface	Instrument Ref. No.
Element identification	X-ray signatures	X-ray spectrometer	O	2
		X-ray solar monitor	O	3
		Vidicon camera	O	4
		Surface solar wind flux	S	None
Element abundance	Sample analysis	(Laboratory)	S	None

- TV camera needed to determine shadow percentage in field of view of X-ray spectrometer
- Surface coverage should be from 70 to 100 percent
- Monitor solar activity during measurements
- Ground truth information would be helpful in answering this question.

Question 2.2

SSB QUESTION

What is the average composition of the rocks on the lunar surface?

Purpose of Question

The identification and the percentage determination of the major chemical elements will provide the basic information required to determine whether and to what extent the moon's surface materials are similar or dissimilar to known materials on Earth. This in turn will provide information on the moon's early history. This may also indicate the amount of foreign material present on the lunar surface, such as meteoritic materials.

Question Interpretation in Terms of Measurable Quantities

In what percentages are the most abundant elements (e.g., silicon, oxygen, magnesium, iron, etc.) present on the surface of the moon?

Definition of Terms

Average Composition - The percentage ratio of the most abundant chemical elements.

Rocks - As used here, means any surface materials.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Element identification	X-ray signatures	X-ray spectrometer	0	2
		Solar X-ray monitor	0	3
		Vidicon camera	0	4
		Surface solar wind flux	S	None
Element abundance	Sample analysis	(Laboratory)	S	None

- Surface coverage should be from 70 to 100 percent
- Ground truth information is essential for this question.

Question 2.3

SSB QUESTION

Are volcanic rocks present on the lunar surface?

Purpose of Question

The identification and determination of the distribution of rock types on the lunar surface will provide information in identifying lunar processes and the extent to which volcanism and other processes have formed and modified the surface and subsurface of the moon.

Question Interpretation in Terms of Measurable Quantities

What is the regional distribution of materials and rock types on the lunar surface (e.g., lava, granite, pyroclastic material, etc.)?

Definition of Terms

Volcanic Rocks - Materials which were derived from the lunar subsurface as molten or ejecta material as a result of volcanic activity.

Rock Types - Classification of lunar material as to type based on physical and mineral properties (e.g., lava, granite, pyroclastic material, etc.).

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Chemical composition	X-ray signatures	X-ray spectrometer	O	2
		X-ray solar monitor	O	3
		TV vidicon camera	O	4
		Surface solar wind flux	S	None
	Sample analysis	(Laboratory)	S	None

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Mineralogical composition	EM signatures	Multispectral imager	O	5
		IR spectrometer	O	7
		UV-Vis spect.	O	6
	Sample analysis	(Laboratory)	S	None
Physical properties	Sample analysis	(Laboratory)	S	None

- Remote sensing imagery measurements should precede spectrometry measurements if they cannot be accomplished simultaneously.
- Ground truth is essential for this question.
- It is assumed that metric photographic coverage will be available for ground reference.

Question 3.1

SSB QUESTION

Is there active volcanism on the moon?

Purpose of Question

A determination of the frequency and magnitude of active volcanism on the moon will provide information in the internal energy, composition of the interior, and the significance of volcanism in forming lunar features. It may provide substantial gains in our understanding of volcanic processes by comparative studies between lunar and terrestrial volcanism.

Question Interpretation in Terms of Measurable Quantities

Is there at least one location on the moon where there are volcanic gases and materials presently being expelled or which exhibit a temperature anomaly sufficiently large to indicate possible active volcanism?

Definition of Terms

Volcanism - Volcanic power or activity includes: processes resulting in the formation of volcanoes, lava flows, laccoliths, stocks, dikes, etc.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Products of volcanism (molten material, gases, temp. anomalies)	Thermal mapping	IR radiometer	O	8
	Gas analysis	IR, Vis, UV gas spectrum analyzer	O	9
Seismic activity	Seismometry	Passive seismometers	S	None

- Thresholds of 500°C and 10^8 mol/cc have been designated for this question.
- These threshold detectors should be included on all missions.

Question 3.2

SSB QUESTION

Is the moon seismically active?

Purpose of Question

Lunar seismic activity (moonquakes) reflects the magnitude of strain accumulation and release, the lunar thermal history, and the current thermal tectonic regime. Seismicity is also directly related to the origin of some surface features, such as faults and craters.

Question Interpretation in Terms of Measurable Quantities

Are there internally generated seismic vibrations detectable at the surface of the moon?

Definition of Terms

Seismic - Pertaining to, characteristic of, or produced by quakes or vibrations.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Seismic activity	Seismometry	Passive seismometers	S	None

Question 3.3

SSB QUESTION

What is the present heat flow at the lunar surface?

Purpose of Question

The determination of heat flow will assist in comparing the moon and the Earth for similarity in composition, relative ages of the two bodies, internal heating processes, and possibly information on the origin of the moon and Earth. It will also support or complement other geophysical and geochemical measurements.

Question Interpretation in Terms of Measurable Quantities

What are the temperature gradients (horizontal and vertical) and thermal conductivities as a function of depth below the surface within the maria and highlands?

Definition of Terms

Heat Flow - The transfer of heat vertically from the interior to the surface and horizontally within the surface but excluding diurnal effects.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Subsurface thermal flux	Subsurface temp. gradient	Temperature probes	S	None
Thermal conductivity	Sample analysis	(Laboratory)	S	None

- Surface measurements are required for answering this question.
- Lunar orbiters cannot provide direct measurement of heat flow. Thermal mapping at shallow depths if available from other questions may be of some value.

Question 3.4

SSB QUESTION

What is the present tectonic pattern?

Purpose of Question

The mapping of the present tectonically active areas on the moon will provide data on the present tectonic pattern and identify areas best suited for the investigation of currently active geologic processes.

Question Interpretation in Terms of Measurable Quantities

Where on the moon is the crust now being deformed as a result of tectonic processes (volcanism, quakes, folding, subsidence processes, etc.)?

Definition of Terms

Tectonic Pattern - Pertains to the locations where the lunar crust is presently being deformed by tectonic processes.

Tectonic Processes - The large scale events or processes which relieve stress within the moon (i.e., volcanism, quakes, subsidence, etc.)

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Active areas	Seismometry	Passive seismometers	S	None
	Temp. mapping	IR radiometer	O	10
	Active seismic	Active seismometers	S	None
Rock structure	Topographic mapping	Med-Hi res. camera	O	13
	Surf. geological mapping	N/A	S	None

• Lunar Orbiter Block I and II type cameras may fulfill photographic requirements.

- It is assumed that the metric camera will be used for topographic mapping.
- Temperature mapping can only indicate and possibly isolate active areas. These areas must then be investigated by surface missions.
- Dark side measurements required in order to provide sufficient time for cooling of the lunar surface.
- Radar does not appear to offer any additional advantage in mapping present tectonic activity. It has limited potential in detecting subsurface structure and surface angularity.

Question 3.5

SSB QUESTION

What are the dominant processes of erosion, transport, and deposition of material on the lunar surface?

Purpose of Question

The identification of the processes responsible for leveling of the lunar surface will assist in evaluating the amount of modification of the lunar surface throughout geologic time and can assist in establishing relative ages of features and materials. (The amount and type of erosion for a given area can indicate older and younger materials.)

Question Interpretation in Terms of Measurable Quantities

What are the principal denudation processes now acting on the lunar surface?

Definition of Terms

Transport - The shifting of material from one place to another.

Erosion - The gradual smoothing of the surface topography.

Denudation - The sum of the processes that result in the wearing down of the surface.

Deposition - The processes of laying down material.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Slumping, solar wind, micrometeorite flux	Sample analysis	(Laboratory)	S	None
	Environmental monitoring	Surface micrometeorite detector, plasma probe, cosmic ray, etc.	S	None
	Surface topography	Med-Hi res. cameras	O	13

- Photography is used in support of deducing erosion, transport and deposition processes.
- It is assumed that the metric camera will be used for topographic mapping.
- Data is best obtained from surface measurements and observations.
- It is assumed that all measurements related to this question will have been made prior to Lunar Orbiter Block III.

Question 3.6

SSB QUESTION

What is the distribution of tectonic activity?

Purpose of Question

The classification of processes as to their type and intensity will provide information pertinent to the extent of surface modification and activity caused by the various processes. This will also assist in evaluating what part tectonic processes have had in forming and modifying the lunar surface throughout geologic time.

Question Interpretation in Terms of Measurable Quantities

Where are each of the tectonic processes (e.g., volcanism, quakes, folding, etc.) occurring on the moon? And to what extent and with what intensity are they occurring?

Definition of Terms

Distribution of Tectonic Activity (Present) - The locations of each type of tectonic activity in operation within the lunar surface.

Tectonic Processes - See Question 3.4 for definition.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Tectonic processes	Thermal mapping	IR radiometer	O	10
Intensity	Seismometry	Passive seismometry	S	None
Extent	Photo mapping	Med-Hi res. cameras	O	13

- The temperature mapping can only indicate and possibly isolate active areas. These areas must then be investigated by surface missions.

- Photographic mapping can utilize medium and high resolution such as can be accomplished by Block I and II.
- The active volcanism detectors (Question 3.1) may contribute to determining the present tectonic pattern.

Question 3.7

SSB QUESTION

What volatile substances are present on or near the surface of the moon or in the transitory lunar atmosphere?

Purpose of Question

A knowledge of the gases near the moon's surface will assist in identifying mechanisms which are responsible for supplying and depleting the lunar atmosphere (e.g., sputtering, rocket exhaust, etc.).

Question Interpretation in Terms of Measurable Quantities

What are the gases and in what abundances are the principal ones present in the lunar atmosphere?

Definition of Terms

Lunar Atmosphere - The volume above the lunar surface where the gas is different in composition or density from that in the surrounding interplanetary space.

Volatile Substances - Atoms, ions, and molecules.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Atmos. gases (neutral atoms, molecules, & ions)	Gas analysis	Mass spectrometer	O	11
	Pressure detection	Pressure gauge	O	12

- The atmospheric gas detectors should be included on all missions for continuous monitoring.

Question 3.8

SSB QUESTION

What are the sources of the heat which produce heat flow?

Purpose of Question

The determination of heat sources will identify active internal processes, such as radioactivity, volcanism, compression and strain, and to evaluate the amount of present and past thermal activity.

Question Interpretation in Terms of Measurable Quantities

What are the internal sources of heat which produce heat flow (e.g., radioactivity, stress, hot core, igneous activity, etc.)?

Definition of Terms

Sources of Heat - The heat generating processes active within the moon.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Radioactivity	Sample analysis	(Laboratory)	S	None
Internal structure	Seismometry	Passive seismometer	S	None
Tectonic activity	Topographic mapping	Med-Hi res. cameras	O	13
	Thermal mapping	IR radiometer	O	10
Heat flow	Temp. gradient	(Laboratory)	S	None
	Temp. conductivity	(Laboratory)	S	None

° It assumed the metric camera will be used for topographic mapping.

Question 3.9

SSB QUESTION

Does the moon have an internally produced magnetic field?

Purpose of Question

It is desirable to determine if the moon has an inherent magnetic field. Any evidence of remnant fields could provide information on the lunar magnetic history. Measurements of the intensity and direction of the total field vector over a long period with coordinated measurements of charged particle flux on the lunar surface may permit separation of the induced magnetic field, and the inherent field.

Question Interpretation in Terms of Measurable Quantities

What is the shape of the magnetic field on and around the moon and how is it related to the interplanetary field?

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Magnetic field	Magnetic vectors	Magnetometer	S	None
Solar wind	Solar wind flux	Plasma probe	S	None

- If orbital measurements are shown to be necessary for this question, an IMP would seem to be a more appropriate spacecraft than LOB III.

Question 4.1

SSB QUESTION

What is the range of age of the stratigraphic units on the lunar surface?

Purpose of Question

The determination of the stratigraphic column (mapping or rock units as to their relative and absolute ages) will provide essential information in the determination of the geologic history and sequence of events on the moon.

Question Interpretation in Terms of Measurable Quantities

What age periods are represented by the rock units (stratigraphic column) at the lunar surface?

Definition of Terms

Stratigraphic Units - Distinct rock units which represent the conditions of their deposition, character, age, and distribution.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Age of rock samples	Radioactive dating	(Laboratory)	S	None
Rock unit distribution	EM signatures & spectra	X-ray spect., X-ray solar monitor, vidicon surface solar wind flux, multispectral imager, IR spectrometer, UV,Vis spectrometer	O	2,3,4,5,6,7
Rock unit relationship	Surface geo. mapping	N/A	S	None
	Photo mapping	Med-Hi res. camera	O	13

- It is assumed that metric photographic coverage will be available for ground reference.
- Radioactive age of rock units and their relationship must be determined by surface missions.

Question 4.2

SSB QUESTION

What past magnetic fields are recorded in the rocks at the moon's surface?

Purpose of Question

Evidence of a past magnetic field can provide information on the moon's geologic history.

Question Interpretation in Terms of Measurable Quantities

What magnetic fields are detectable in samples of the lunar surface?

Definition of Terms

Past Magnetic Fields - Those localized magnetic fields which are permanent results of previous magnetism.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Paleomagnetism	Sample analysis	(Laboratory)	S	None

- Samples of the surface with orientation carefully recorded are necessary.

Question 4.3

SSB QUESTION

Is there evidence of organic or proto-organic material on or near the lunar surface?

Purpose of Question

Evidence of organic material on the lunar surface would be valuable in determining the past relationship of the moon to the Earth and uniqueness of life on Earth.

Question Interpretation in Terms of Measurable Quantities

Are there compounds on the lunar surface which are indicators of a biological evolution (e.g., ammonia, water, amino acids, proteins, etc.)?

Definition of Terms

Organic - Those chemical substances thought to be precursors of living cells (i.e., amino acids, proteins, etc.)

Proto-organic - Those substances thought to be necessary to the formation of organic molecules (i.e., carbon, methane, ammonia, water, etc.).

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Pre-biological compounds	Sample analysis	(Laboratory)	S	None

- Samples of the surface are necessary.

Question 4.4

SSB QUESTION

Are there living organisms present on or beneath the lunar surface?

Purpose of Question

The determination of whether there is any living matter on or within the lunar surface will provide valuable information concerning the origin and evolution of life in the solar system.

Question Interpretation in Terms of Measurable Quantities

Are there living organisms present on or beneath the lunar surface?

Definition of Terms

Living Organisms - Something capable of information storage, reproduction, and the controlled transfer of energy.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Living organisms	Sample analysis	(Laboratory)	S	None

- Samples of the surface materials are necessary.

Question 4.5

SSB QUESTION

Is there a fundamental difference in morphology and history between the sub-Earth and averted faces of the moon?

Purpose of Question

Any basic differences in morphology between the two faces of the moon is fundamental in interpreting the history of the development of the moon and its relationship to the Earth, and in evaluating whether internal and external processes have been uniformly active around the moon.

Question Interpretation in Terms of Measurable Quantities

Are the land masses (e.g., maria and highlands) on the backside of the moon different in appearance, distribution, ~~and elevation to those~~ on the sub-Earth face such that the two sides may have different histories?

Definition of Terms

Morphology - The general configuration and distribution of surface features which indicates something about their history.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instrument	Orbit or Surface	Instrument Ref. No.
Land form types	Topographic mapping	Low resolution camera	0	13
Land mass elevation	Altimetry	Radar altimeter	0	1

- It is assumed that LOB I and II cameras and the Block III camera will provide sufficient data to answer this question.

Question 4.6

SSB QUESTION

What are the principal processes responsible for the present relief of the lunar surface?

Purpose of Question

The identification of the principal processes which are responsible for forming lunar features will provide valuable information as to the evolutionary history of the development and modification of the lunar surface and interior.

Question Interpretation in Terms of Measurable Quantities

What are the principal processes responsible for the present relief of the lunar surface (e.g., volcanism, impacting, folding, faulting, denudation, etc.)?

Definition of Terms

Processes - Those events which form the external features of a body (i.e., volcanism, impacting, folding, faulting, denudation, etc.).

Relief - The relative elevations of the topography at the surface.

Lithologic Unit - A rock unit which represents a uniform condition during deposition or formation.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Lithologic units	Surface geo. mapping	N/A	S	None
	X-ray signatures	X-ray spec.	O	2
		X-ray solar monitor	O	3
		Vidicon camera	O	4
		Surface solar wind flux	S	None

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
	Sample analysis	(Laboratory)	S	None
	EM signatures	Multispect. imager	0	5
		IR spectrometer	0	7
		UV, vis. spect.	0	6
	Thermal mapping	IR radiometer	0	10
Structural features	Surface geo. mapping	N/A	S	None
	Seismometry	Active seismometer	S	None
	Gravimetry	Gravimeter	S	None
Surface relief	Topographic mapping	Low-med res. camera	0	13

- The identification of processes responsible for lunar relief is primarily obtained from surface measurements and observations.

- It is assumed that the metric camera will be used for surface topography

Question 4.7

SSB QUESTION

What is the age of the moon?

Purpose of Question

The age dating of the lunar materials assists in the comparison of lunar and terrestrial materials.

Question Interpretation in Terms of Measurable Quantities

What is the best estimate of the moon's age based on dating of materials?

Definition of Terms

Age - The age of the moon, based on the oldest material that can be dated.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Age of samples	Radioactive age of samples	(Laboratory)	S	None
Strati-graphic units	Surface geo. mapping	N/A	S	None
	X-ray signatures	X-ray spec.	O	2
		X-ray solar monitor	O	3
		Vidicon camera	O	4
		Surface solar wind flux	S	None
	EM signatures	Multispec. imager	O	5
		IR spectrometer	O	7
		UV, vis. spect.	O	6

- It is assumed that metric photography will be used for this question.

SSB QUESTION

Is a primordial surface exposed on the lunar surface?

Purpose of Question

The sampling of primordial material will assist in establishing an approximate age of the moon, its rate of cooling into solid rock, and a complete stratigraphic column. If the primordial surface is exposed it will provide ease of sampling.

Question Interpretation in Terms of Measurement Quantities

Does the oldest exposed rock unit of the lunar surface represent material which was formed during the initial formation or cooling of the moon?

Definition of Terms

Primordial Surface - That material which represents rocks which were formed during the initial cooling or formation of the moon.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Stratigraphic units	Radioactive age of samples	(Laboratory)	S	None
	Surface mapping	N/A	S	None
	X-ray signatures	X-ray spect.	O	2
		X-ray solar monitor	O	3
		Vidicon camera	O	4
		Surface solar wind flux	S	None
	EM signatures	Multispec. imager	O	5
		IR spectrometer	O	7
		UV, vis. spect.	O	6
Topography	Topographic mapping	Lo-med. res. camera	O	13

- It is assumed that the metric camera will be used for topographic mapping.

Question 4.9

SSB QUESTION

What is the history of dynamical interaction between the Earth and the moon?

Purpose of Question

The dynamical relationship is probably one of the key aspects of the historical relationship between the moon and the Earth.

Question Interpretation in Terms of Measurable Quantities

What has been the dynamical interaction between the moon and Earth during and subsequent to their formation as determined from tidal gravity, density distribution, departure from fluid equilibrium and librations?

Definition of Terms

Dynamical Interaction - The gravitational relationship (attraction) between the moon and Earth.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Mass distribution	Satellite tracking	N/A	O	None
Shape of moon	Altimeter	Radar altimeter	O	1
Rigidity & elasticity	Seismometry	Passive seismometer	S	None
Tidal forces	Tidal gravimetry	Tidal gravimeter	S	None
Lunar perturbations and librations	Earth-based observations	Corner reflector	S	None

- It is assumed that corner reflectors (Surveyor) will provide adequate information on lunar orbit perturbations and librations.

Question 4.10

SSB QUESTION

What is the thermal history of the moon?

Purpose of Question

The answering of the thermal history question will help determine how the moon was initially formed, its past relationship to the Earth and Sun, and its past internal energy pattern.

Question Interpretation in Terms of Measurable Quantities

Do stratigraphic units, structural features, and heat flow of the moon indicate whether it is heating up or cooling down?

Definition of Terms

Thermal History - The temperature of the moon during its formation, and subsequent changes.

Tectonic Activity - Pertaining to the rock structure and external forms as a result of deformation of the crust from volcanism, quakes, subsidence, folding, or uplifting.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Strati-graphic units	Radioactive age of samples	(Laboratory)	S	None
	Surface geo. mapping	N/A	S	None
	X-ray signatures	X-ray spect.	O	2
		X-ray solar monitor	O	3
		Vidicon camera	O	4
		Surface solar wind flux	S	None
	EM signatures	Multispec. imager	O	5
		IR spectrometer	O	7
	Thermal mapping	IR radiometer	O	10

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Structural features	Surface geo. mapping	N/A	S	None
	Seismometry	Active seismometer	S	None
	Gravimetry	Gravimeter	S	None
	Topographic mapping	Lo-med. res. camera	O	13
Heat flow	Temp. gradient	Subsurface probes	S	None
	Thermal conductivity	(Laboratory)	S	None

- It is assumed that metric photography will be used for this question.
- The information required for the stratigraphic units, structural features, and heat flow should be obtained from the surface.

Question 4.11

SSB QUESTION

What has been the distribution of tectonic activity?

Purpose of Question

Tectonic features as to type, size, and period of occurrence will provide information on the evolutionary history of the moon and what processes have been most active during any given period of lunar geologic time.

Question Interpretation in Terms of Measurable Quantities

How have lunar tectonic processes (volcanism, folding, faulting, etc.) varied in location and activity during the past as determined from structural, topographic, and stratigraphic relationships and the present tectonic pattern?

Definition of Terms

Distribution of Tectonic Activity (Past) - The locations and magnitude of tectonic activity in relationship to geologic time.

Tectonic Activity - See Question 4.10 for definition.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Strati-graphic units	Surface geo. mapping	N/A	S	None
	Sample analysis	(Laboratory)	S	None
	X-ray signatures	X-ray spect.	O	2
		X-ray solar monitor	O	3
		Vidicon camera	O	4
		Surface solar wind flux	S	None
	EM signatures	Multispec.imager	O	5
		IR spectrometer	O	7
		UV-vis. spect.	O	6
	Thermal mapping	IR radiometer	O	10
Topographic features	Topographic mapping	Low-med. res. camera	O	13

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Structural features	Surface geo. mapping	N/A	S	None
	Seismometry	Active seismometer	S	None
	Gravimetry	Gravimeter	S	None

- It is assumed that the metric camera used for LOB III will be used for this question.

Question 4.12

SSB QUESTION

What has been the distribution of volcanic activity?

Purpose of Question

The answer to this question would provide information on the relationship between the surface configuration, thermal history, the concentration of heat generating elements, and also information on tectonic distribution to volcanic activity.

Question Interpretation in Terms of Measurable Quantities

What has been the location and magnitude of volcanic activity during any period of lunar geologic time as determined by stratigraphic units and structural features?

Definition of Terms

Distribution of Volcanic Activity - The location and magnitude of volcanic activity during any given period of lunar geologic time.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Stratigraphic units	Surface geo. mapping	N/A	S	None
	X-ray signatures	X-ray spect.	O	2
		X-ray solar monitor	O	3
		Vidicon camera	O	4
		Surface solar wind flux	S	None
	EM signatures	Multispec. imager	O	5
		IR spectrometer	O	7
		UV-vis. spect.	O	6
	Thermal mapping	IR radiometer	O	10
Structural features	Surface geo. mapping	N/A	S	None
		Active seismometer	S	None
	Gravimetry	Gravimeter	S	None
Crater appearance	Topographic mapping	Lo-med. res. camera	O	13

- Surface measurements are required for mapping structural features and stratigraphic relationships.
- It is assumed that the metric photography will be used for this question.

Question 4.13

SSB QUESTION

What has been the flux of solid objects striking the lunar surface in the past and how has it varied with time?

Purpose of Question

The determination of the approximate number of objects striking the lunar surface by size, origin (i.e., meteorites and ejecta material) and velocity will assist in estimating the overall effect that impacting objects have had on modifying and forming surface features.

Question Interpretation in Terms of Measurable Quantities

How has the impact crater population varied with geologic time as determined from crater appearance and the relationship between foreign (meteoritic) and indigenous (lunar surface) materials?

Definition of Terms

Flux - The number and rate of solid objects (foreign and/or indigenous) striking the lunar surface.

Foreign Objects - Any extra lunar meteorite which impacts the lunar surface (i.e., meteorites).

Indigenous Objects - Material derived from the lunar surface and ejected by volcanic or meteoritic explosions.

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Stratigraphic units	Surface geo. mapping	N/A	S	None
	Sample analysis	(Laboratory)	None	None
	X-ray signatures	X-ray spect.	O	2
		X-ray solar monitor	O	3
		Vidicon camera	O	4
		Surface solar wind flux	S	None

Measurement Parameters	Technique of Measurements	Instrument	Orbit or Surface	Instrument Ref. No.
	EM signatures	Multispec. imager	O	5
		IR spectrometer	O	7
		UV-vis. spect.	O	6
	Thermal mapping	IR radiometer	O	7,10
Structural features	Surface geo. mapping	N/A	S	None
	Seismometry	Active seismometer	S	None
	Gravimetry	Gravimeter	S	None
Topographic features	Topographic mapping	Lo-med. res. camera	O	13

- The answer to this question will come primarily from surface measurements and observations.

Question 4.14

SSB QUESTION

What has been the flux of cosmic radiation and high-energy solar radiation over the history of the moon?

Purpose of Question

Knowledge of the past high-energy radiation bombarding the moon will assist in determining its geologic history.

Question Interpretation in Terms of Measurable Quantities

What evidence is there on the moon of the past influx of radiation from outer space?

Definition of Terms

Cosmic Radiation - Very high-energy charged particles with high-penetrating power coming from interstellar space.

Solar Radiation - Highly penetrating particles (protons) emitted from the Sun by large solar eruptions (solar flares).

Measurement Requirements

Measurement Parameters	Technique of Measurements	Instruments	Orbit or Surface	Instrument Ref. No.
Strati-graphic units	Surface geo. mapping	N/A	S	None
	Isotopic ratios of samples	(Laboratory)	S	None
	X-ray signa-tures	X-ray spect.	O	2
		X-ray solar monitor	O	3
		Vidicon camera	O	4
		Surface solar wind flux	S	None
	EM signatures	Multispec. imager	O	5
		IR spectrometer	O	7
		UV-vis. spect.	O	6

- Surface measurements are required to answer this question.